COSMO application over New Zealand: An evaluation using in-situ aircraft measurements

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Introduction: During the international aircraft measurement campaign DEEPWAVE (Deep Propagating Gravity Wave Experiment) in July 2014, one flight has been performed to investigate stratosphere-troposphere-exchange (STE) in the vicinity of a tropopause folding event over New Zealand. Since STE-events along tropopause folds are known to influence tropospheric chemistry e.g. by transporting stratospheric, ozone-rich airmasses into the troposphere, it is important to analyse these events in detail. Therefore we use MESSy to couple the COSMO model with the global model ECHAM5/MESSy for Atmospheric Chemistry (EMAC). Hereby, we have the possibility to calculate consistent chemistry on global and regional scales. Additionally, MESSy enables the release of artificial, passive tracers under defined conditions which are helpful to determine the origin of different airmasses, time scales and regions of exchange. Applying COSMO over New Zealand the first time, the evaluation of the meteorological situation is crucial. This is done by comparing the synoptic situation with ECMWF analyses and airborne meteorological data. Subsequently, measurements of several trace gases can be analysed using the results of the model system.

Synoptic situation:

- Low pressure system is located south-eastward of New Zealand (Fig. 1a,b).
- Cold front, associated with a distinct tropopause fold (Fig. 5), has already passed.
- Through is situated above New Zealand (Fig. 1c).

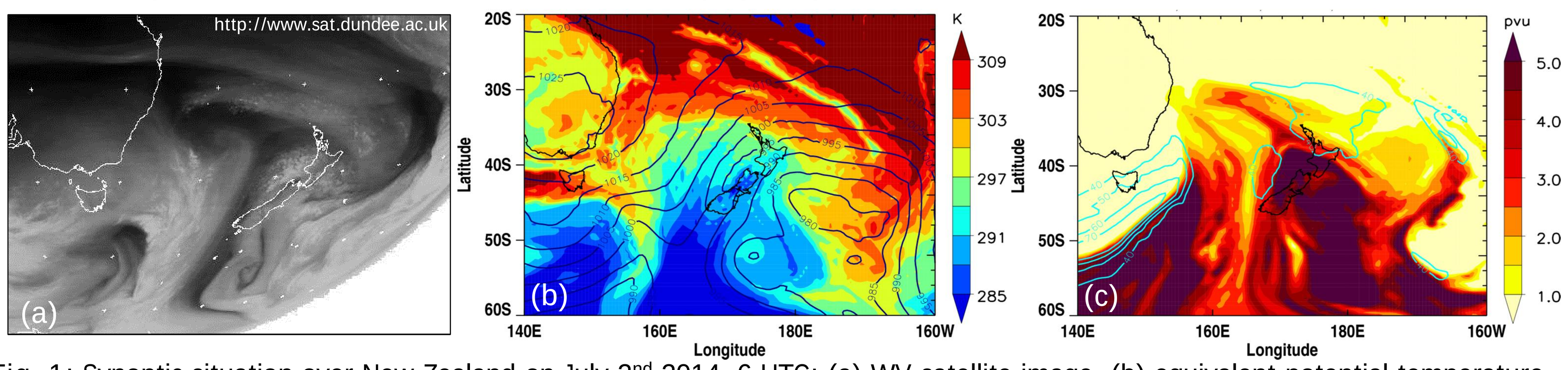

Fig. 1: Synoptic situation over New Zealand on July 2nd 2014, 6 UTC: (a) WV-satellite image, (b) equivalent potential temperature (θ_e, in K, colour) and mean sea level pressure (in hPa, contours) at 850 hPa and (c) potential vorticity (PV, in pvu, colour) and horizontal wind velocity (in m/s, contours) at 315K-isentrope for ECMWF-analyses.

Model set-up and simulations:

- COSMO/MESSy is driven on-line by the global model EMAC resp. a coarser COSMO/MESSy instance.
- Here: Setup with two COSMO/MESSy instances (Tab. 1, Fig. 2)
- The driving instance provides boundary data every time step.
- SIM A and SIM B differ in their vertical resolutions (L40 (operational) vs. L61 (higher resolved in UTLS-region, Eckstein et al., 2015).

	ECHAM5	COSMO4.8/MESSy_02	COSMO4.8/MESSy_03
SIM A	T106L31, 6min	0.125°L40, 2min	0.0625°L40, 40s
SIM B	T63L47MA, 6min	0.125°L61, 2min	0.0625°L61, 40s

Tab. 1: Set-up of the model system. Indicated are spatial resolution and timestep for each model instance.

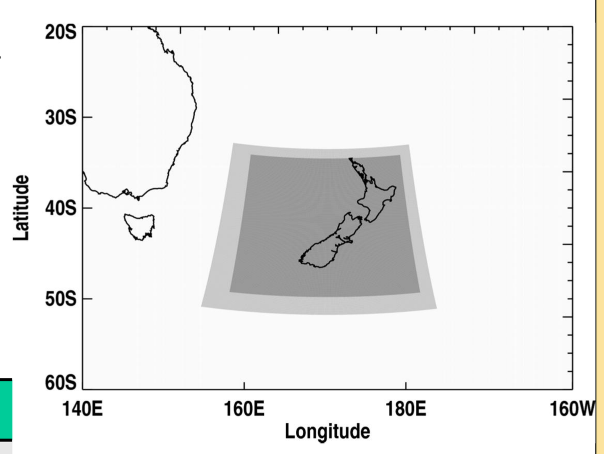

Fig. 2: Regions of the COSMO/MESSy instances with 0.125° resolution (light grey) and 0.0625° resolution (dark grey).

Results of different resolved model instances compared with ECMWF analyses:

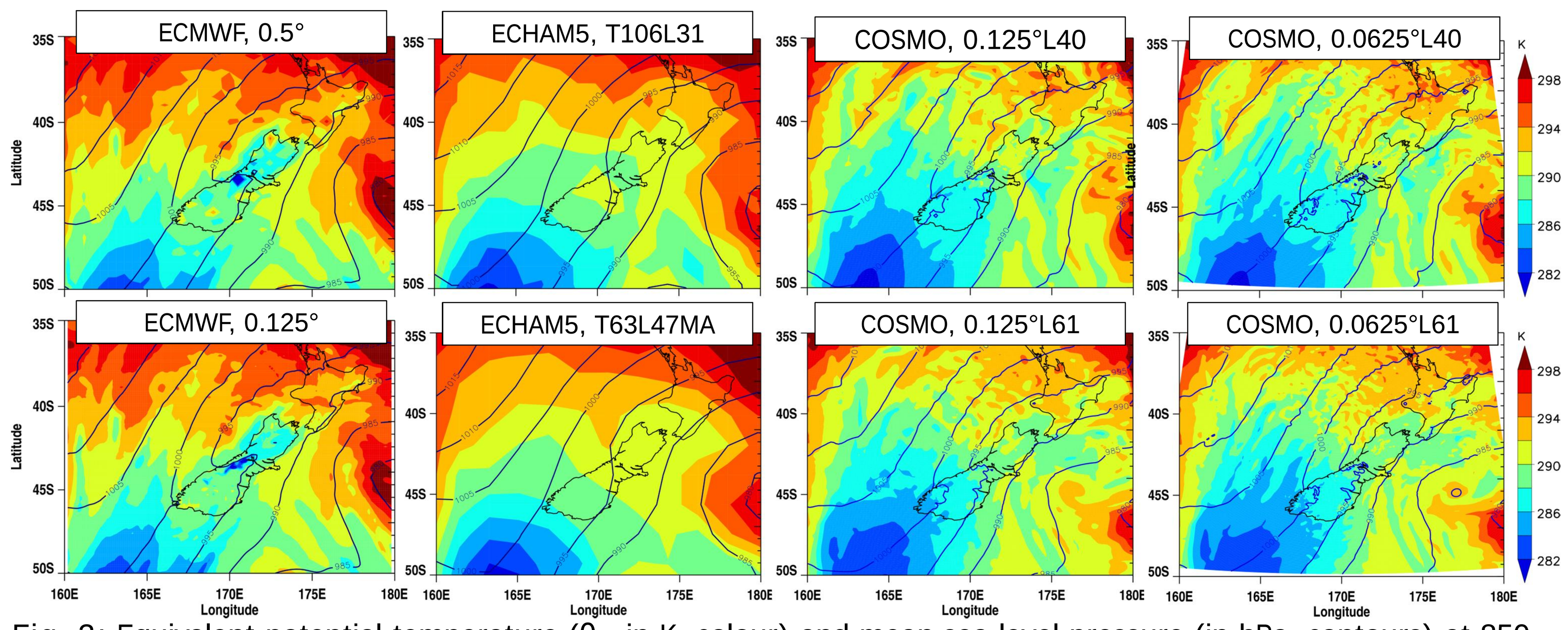

Fig. 3: Equivalent potential temperature (θ_e, in K, colour) and mean sea level pressure (in hPa, contours) at 850 hPa for ECMWF analyses and the model instances with different resolutions.

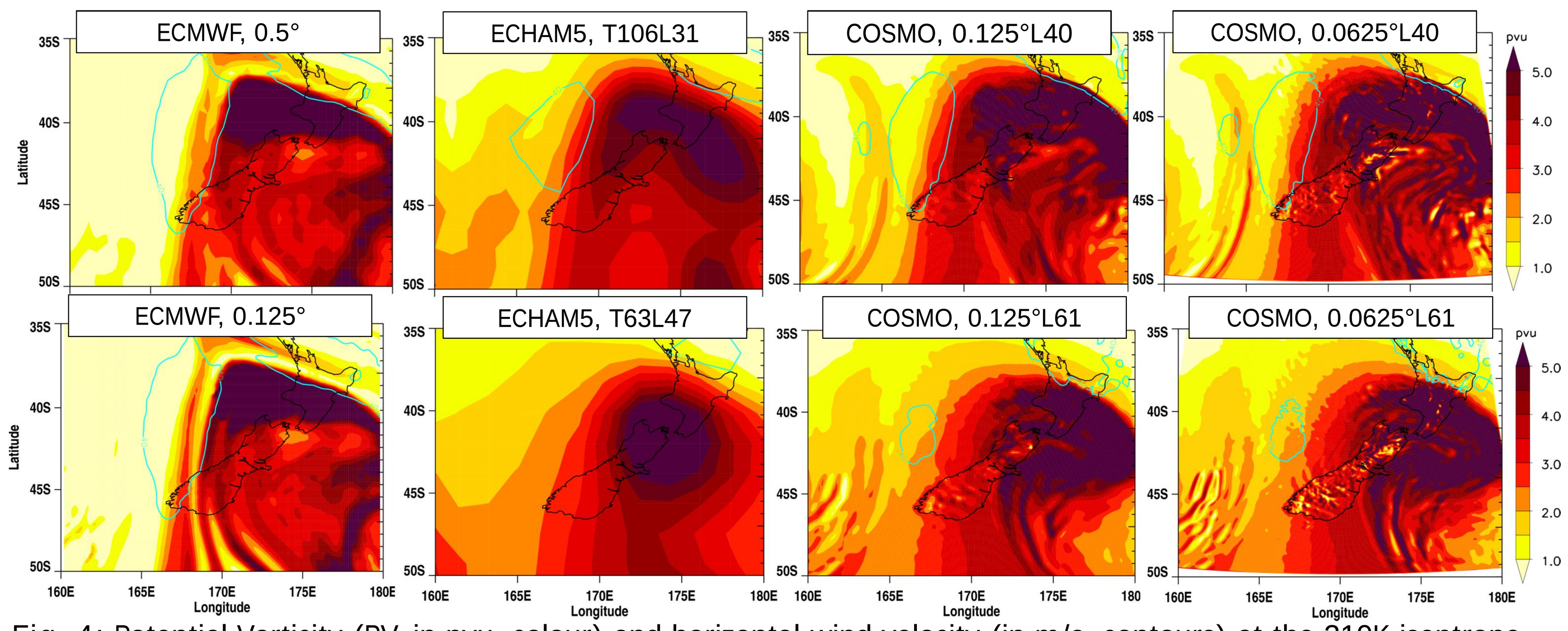

Fig. 4: Potential Vorticity (PV, in pvu, colour) and horizontal wind velocity (in m/s, contours) at the 310K-isentrope for ECMWF analyses and the model instances with different resolutions.

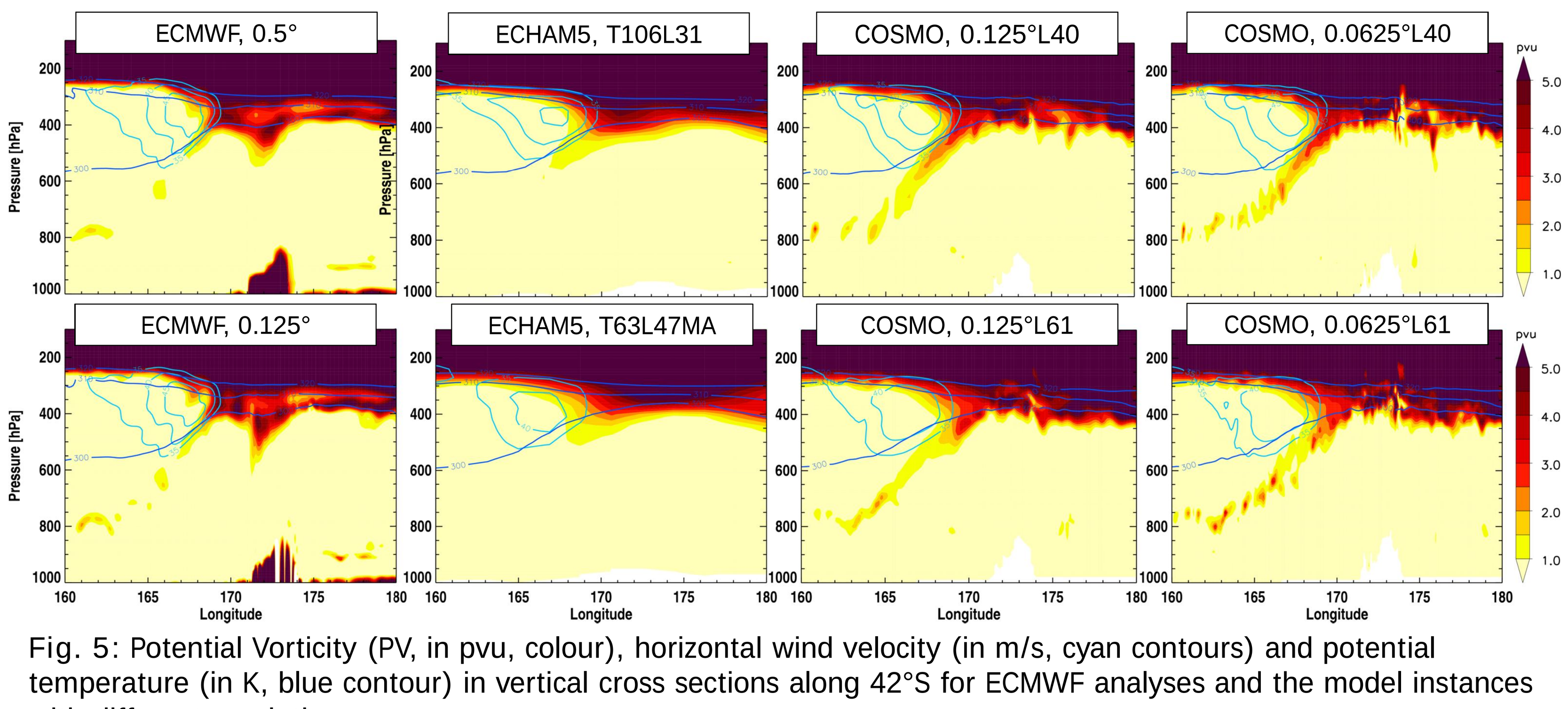

Fig. 5: Potential Vorticity (PV, in pvu, colour), horizontal wind velocity (in m/s, cyan contours) and potential temperature (in K, blue contour) in vertical cross sections along 42°S for ECMWF analyses and the model instances with different resolutions.

➢ The overall synoptic situation in the region of New Zealand is captured by all model instances.

Nevertheless, compared to ECMWF analyses, there are some deviations:

- COSMO/MESSy instances show slightly colder temperatures at 850 hPa (Fig. 3).
- In the western region, the 310K-isentrope is located below the dynamical 2pvu-tropopause in the analyses, whereas the modeled PV-values are higher (Fig. 4, Fig. 5).
- The tropopause fold, associated with the jetstream, is most pronounced in the COSMO/MESSy instance with highest resolution (Fig. 5).
- The jetstream is less intense in the model instances with higher vertical resolution (Fig. 5).

Evaluation of the model results using in-situ aircraft measurements:

Flight track:

- take-off in Christchurch at July 2nd, 5:48 UTC
- south-westerly track (Fig. 6b) with varying flight levels (Fig. 6a)
- crossing the backside of the through, associated with a tropopause fold, four times
- landing in Christchurch at July 2nd, 9:21 UTC

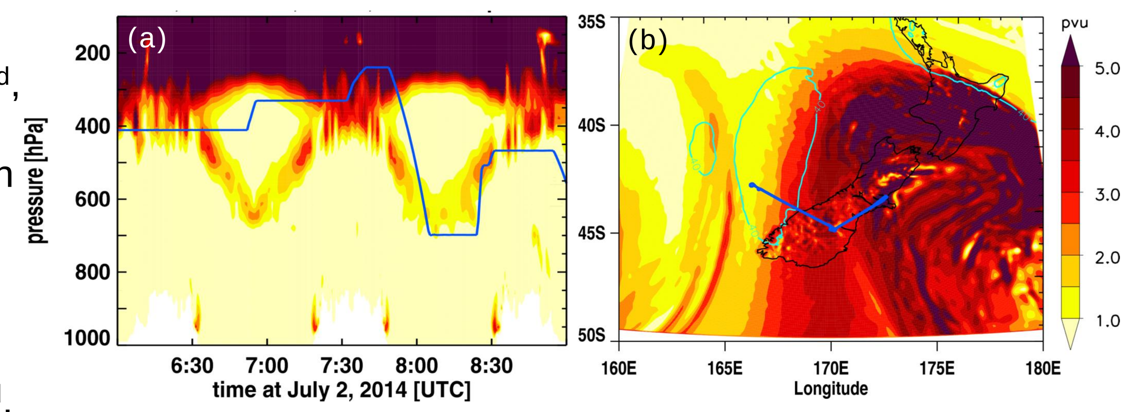

Fig. 6: Flight track (blue contour) in a vertical cross section along the flight track (a) and at the 310K-isentrope (b). PV is show in coulour.

Meteorological data:

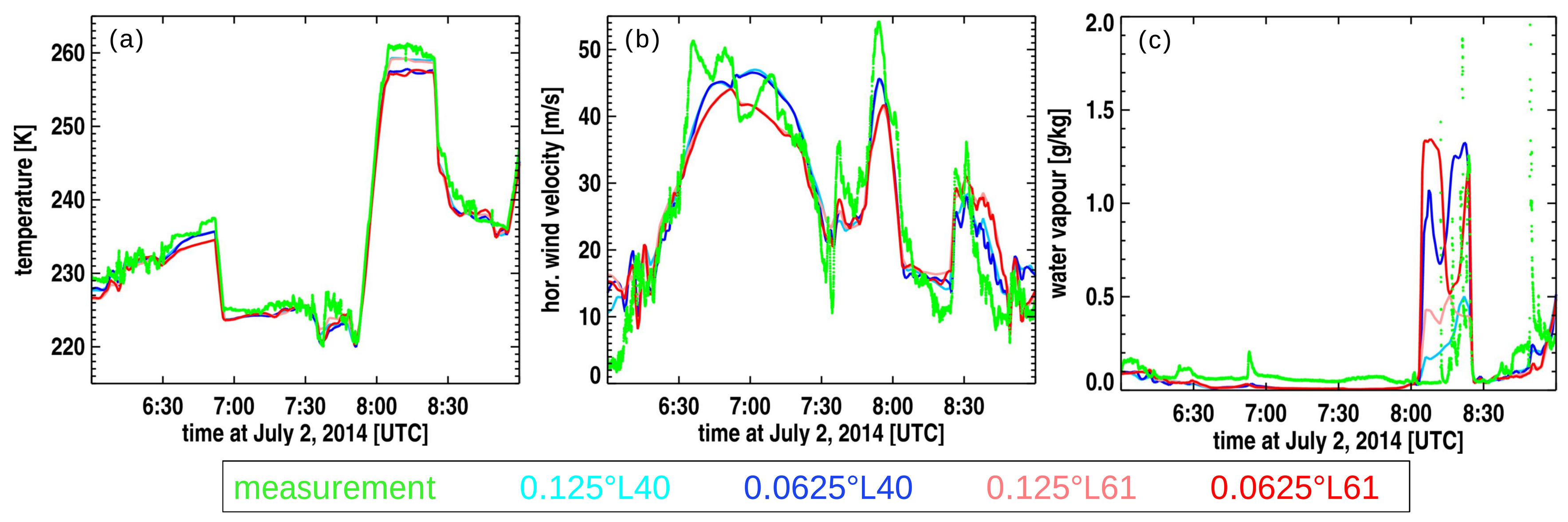

Fig. 7: Meteorological variables during the flight in measurements (green) and for the model instances with different resolutions. The model data has been on-line interpolated along the flight track every time step.

➢ The model results of the COSMO/MESSy-instances coincide well with the measurements.

It is impossible to determine the resolution the COSMO/MESSy instance performs best with:

- Instances with lower horizontal resolution capture the temperature maximum best (Fig. 7a).
- Wind maxima are represented better in the instances with less vertical resolution (Fig. 5, Fig. 7b) (this might be due to the coarse horizontal resolution of the driving instance).
- All instances show the increase in specific humidity at 8:15 UTC due to the occurrence of clouds (not shown) too soon, the instances with lower horizontal resolution also underestimate it.

Tracer:

N_2O is a tropospheric tracer, which is almost homogenous distributed in the troposphere. In July 2014, the tropospheric mixing ratio of N_2O was 327±0.5 ppbv. In the stratosphere the mixing ratio decreases with height.

STRATO is an artificial tracer, which has been initialised in the stratosphere (PV>2 pvu, QV<1 g/kg) at the beginning of the simulation with 100 ppbv.

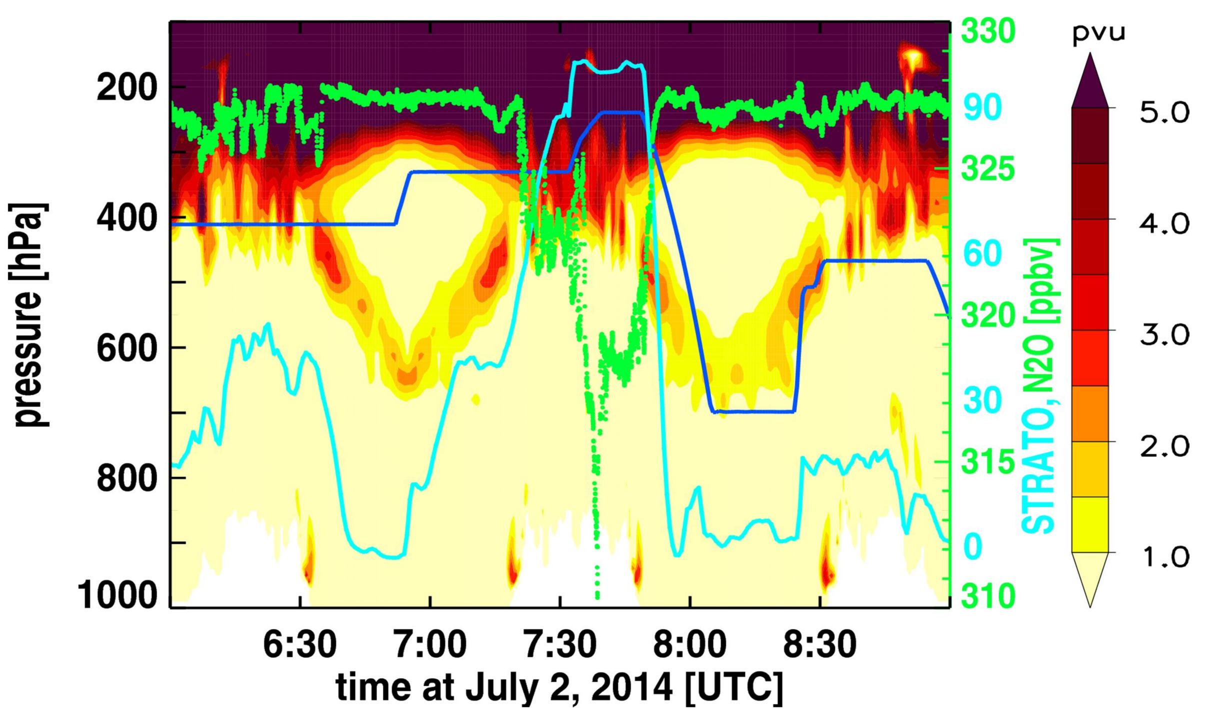

Fig. 8: Variables along the flight track. PV (in colour, pvu), flight track (blue contour), measured N_2O-Tracer (green, ppbv) and modeled, artificial stratospheric tracer STRATO (cyan, ppbv). Results are shown for COSMO/MESSy with 0.125°L40 resolution.

➢ Modelled and measured tracer coincide: Almost every time the measured N_2O-Tracer shows a stratospheric signal (< 327 ppbv), the simulated stratospheric tracer shows also a signal (> 0 ppbv).

- That way it is possible to identify mixing regions, where the air masses have both, stratospheric and tropospheric, signatures.
- Here, mixing regions can be identified before 6:30 UTC, in a region with a disturbed tropopause, and when crossing the tropopause fold (7:50 UTC and 8:20 UTC).

Conclusion and Outlook:

- Due to the additional options in COSMO/MESSy (initialisation of passive tracers, on-line-interpolation of data along the flight track), the model system is well-suited to analyse in-situ aircraft measurements.
- Independent of the spatial resolution COSMO/MESSy is able to capture the synoptic situation in the region of New Zealand.
- Tracers along the flight track indicate mixing regions along the tropopause fold, where stratosphere-to-troposphere-exchange (STE) occurred.
- The reasons and processes of these STE-events can now be analysed with the help of the model data.
- Full chemistry calculation might be helpful to interpret further tracer measurements.